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Title:

“Evaluation of Start Transient Oscillations with the J-2X Engine Gas Generator Assembly”

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Abstract:

During development of the gas generator for the liquid oxygen/liquid hydrogen propellant J-2X rocket engine, distinctive and oftentimes high-amplitude pressure oscillations and hardware vibrations occurred during the start transient of nearly every workhorse gas generator assembly test, as well as during many tests of engine system hardware. These oscillations appeared whether the steady-state conditions exhibited stable behavior or not. They occurred similarly with three different injector types, and with every combustion chamber configuration tested, including chamber lengths ranging over a 5:1 range, several different nozzle types, and with or without a side branch line simulating a turbine spin start gas supply line. Generally, two sets of oscillations occurred, one earlier in the start transient and at higher frequencies, and the other almost immediately following and at lower frequencies. Multiple dynamic pressure measurements in the workhorse combustion chambers indicated that the oscillations were associated with longitudinal acoustic modes of the combustion chambers, with the earlier and higher frequency oscillation usually related to the second longitudinal acoustic mode and the later and lower frequency oscillation usually related to the first longitudinal acoustic mode. Given that several early development gas generator assemblies exhibited unstable behavior at frequencies near the first longitudinal acoustic modes of longer combustion chambers, the start transient oscillations are presumed to provide additional insight into the nature of the combustion instability mechanisms. Aspects of the steady-state oscillations and combustion instabilities from development and engine system test programs have been reported extensively in the three previous JANNAF Liquid Propulsion Subcommittee meetings (see references below). This paper describes the hardware configurations, start transient sequence operations, and transient and dynamic test data during the start transient. The implications of these results on previous analyses and understanding of the combustion instability observed during steady-state conditions, especially the effects of injector influences, is discussed.

1. Reynolds, D., Kopicz, C., and Hormozian, C., "J-2X Gas Generator Development Testing at NASA Marshall Space Flight Center," 57<sup>th</sup> JANNAF Propulsion Meeting (JPM) and Joint Meeting of the 7<sup>th</sup> Modeling & Simulation Subcommittee (MSS) / 5<sup>th</sup> Liquid Propulsion Subcommittee (LPS) / and 4<sup>th</sup> Spacecraft Propulsion Subcommittee (SPS), Colorado Springs, CO, May 3-7, 2010.
2. Hulka, J.R., Protz, C.S., Casiano, M.J., and Kenny, R.J., "Longitudinal Mode Combustion Stability Analyses for J-2X Gas Generator Development," 57<sup>th</sup> JANNAF Propulsion Meeting (JPM) and Joint Meeting of the 7<sup>th</sup> Modeling & Simulation Subcommittee (MSS) / 5<sup>th</sup> Liquid Propulsion Subcommittee (LPS) / and 4<sup>th</sup> Spacecraft Propulsion Subcommittee (SPS), Colorado Springs, CO, May 3-7, 2010.
3. Hulka, J.R., Protz, C.S., Casiano, M.J., and Kenny, R.J., "Effect of Test Facility Feed Systems on Combustion Instability During J-2X Workhorse Gas Generator Testing," 57<sup>th</sup> JANNAF Propulsion Meeting (JPM) and Joint Meeting of the 7<sup>th</sup> Modeling & Simulation Subcommittee (MSS) / 5<sup>th</sup> Liquid Propulsion Subcommittee (LPS) / and 4<sup>th</sup> Spacecraft Propulsion Subcommittee (SPS), Colorado Springs, CO, May 3-7, 2010.
4. Kenny, R.J., Muss, J.A., Hulka, J.R., and Casiano, M.J., "Effects of Multiple Orifice Exhaust Nozzle Admittance on J-2X Gas Generator Stability," 57<sup>th</sup> JANNAF Propulsion Meeting (JPM) and Joint Meeting of the 7<sup>th</sup> Modeling & Simulation Subcommittee (MSS) / 5<sup>th</sup> Liquid Propulsion Subcommittee (LPS) / and 4<sup>th</sup> Spacecraft Propulsion Subcommittee (SPS), Colorado Springs, CO, May 3-7, 2010.
5. Reynolds, D.C., and Kopicz, C., "J-2X Workhorse Gas Generator Testing at NASA Marshall Space Flight Center," Joint Meeting of the 8<sup>th</sup> Modeling and Simulation Subcommittee (MSS) / 6<sup>th</sup> Liquid Propulsion Subcommittee (LPS) / 5th Spacecraft Joint Subcommittee (SPS), Huntsville, AL, December 5-9, 2011.
6. Hulka, J.R., Kenny, R.J., Protz, C.S., and Casiano, M.J., "Supplementary Tests and Analyses of Injection-coupled Combustion Stability from J-2X Gas Generator Development," Joint Meeting of the 8<sup>th</sup> Modeling & Simulation Subcommittee (MSS) / 6<sup>th</sup> Liquid Propulsion Subcommittee (LPS) / and 5<sup>th</sup> Spacecraft Propulsion Subcommittee (SPS), Huntsville, AL, December 5-9, 2011.
7. Kenny, R.J., "Spin Start Line Effects on the J-2X Gas Generator Chamber Acoustics," Joint Meeting of the 8<sup>th</sup> Modeling and Simulation Subcommittee (MSS) / 6<sup>th</sup> Liquid Propulsion Subcommittee (LPS) / 5th Spacecraft Joint Subcommittee (SPS), Huntsville, AL, December 5-9, 2011.
8. Hulka, J.R., Kenny, R.J., and Casiano, M.J., "Combustion Stability of the J-2X Gas Generator Assembly from Engine E10001 and Power-pack Tests," 60<sup>th</sup> JANNAF Propulsion Meeting and Joint Meeting of the 9<sup>th</sup> Modeling & Simulation Subcommittee (MSS) / 7<sup>th</sup> Liquid Propulsion Subcommittee (LPS) / and 6<sup>th</sup> Spacecraft Propulsion Subcommittee (SPS) , Colorado Springs, CO, April 29-May 3, 2013.